CHAPTER 2

EPA/NSF ETV EQUIPMENT VERIFICATION TESTING PLAN MEMBRANE PROCESSES FOR THE REMOVAL OF PRECURSORS TO DISINFECTION BY-PRODUCTS

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TABLE OF CONTENTS

		Page
1.0	**APPLICATION OF THIS EQUIPMENT VERIFICATION TESTING PLAN**	2-5
2.0	**INTRODUCTION**	2-5
3.0	**GENERAL APPROACH**	2-6
4.0	**OVERVIEW OF TASKS**	2-6
4.1	Task A: Characterization of Feed Water	2-6
4.2	Task B: Initial Test Runs	2-7
4.3	Task 1: Membrane Flux and Operation	2-7
4.4	Task 2: Cleaning Efficiency	2-7
4.5	Task 3: Finished Water Quality	2-7
4.6	Task 4: Data Management	2-7
4.7	Task 5: QA/QC	2-7
5.0	**TESTING PERIODS**	2-8
6.0	**DEFINITION OF OPERATIONAL PARAMETERS**	2-9
6.1	Permeate	2-9
6.2	Feedwater	2-9
6.3	Concentrate	2-9
6.4	Permeate Flux	2-9
6.5	Specific Flux	2-9
6.6	Membrane Fouling	2-9
6.7	Transmembrane Pressure	2-10
6.8	Temperature Adjustment for Flux Calculation	2-10
6.9	Feedwater System Recovery	2-10
6.10	Membrane Process Recovery	2-10
6.11	Foulants	2-11
6.12	Scaling	2-11
7.0	**TASK A: CHARACTERIZATION OF FEED WATER**	2-11
7.1	Objectives	2-11
7.2	Work Plan	2-11
7.3	Analytical Schedule	2-12
7.4	Evaluation Criteria	2-12
8.0	**TASK B: INITIAL TEST RUNS**	2-12
8.1	Introduction	2-12
8.2	Objectives	2-12
8.3	Work Plan	2-12
8.4	Analytical Schedule	2-13

TABLE OF CONTENTS (continued)

		Page
8.5	Evaluation Criteria	2-13
9.0	**TASK 1: MEMBRANE FLUX AND OPERATION**	2-13
9.1	Introduction	2-13
9.2	Experimental Objectives	2-14
9.3	Work Plan	2-14
9.4	Analytical Schedule	2-15
	7.4.1 Operational Data Collection	2-15
	7.4.2 Feedwater Quality Limitations	2-16
	7.4.3 Waste Stream Water Quality	2-16
9.5	Evaluation Criteria and Minimum Reporting Requirements	2-16
10.0	**TASK 2: CLEANING EFFICIENCY**	2-17
10.1	Introduction	2-17
10.2	Experimental Objectives	2-17
10.3	Work Plan	2-17
10.4	Analytical Schedule	2-18
	8.4.1 Sampling	2-18
	8.4.2 Operational Data Collection	2-18
10.5	Evaluation Criteria and Minimum Reporting Requirements	2-18
11.0	**TASK 3: FINISHED WATER QUALITY**	2-19
11.1	Introduction	2-19
11.2	Experimental Objectives	2-19
11.3	Work Plan	2-20
11.4	Analytical Schedule	2-21
	9.4.1 Removal of Simulated Distribution System Precursors to DBPs	2-21
	9.4.2 Feed and Permeate Water Characterization	2-22
	9.4.3 Water Quality Sample Collection	2-22
	9.4.4 Feedwater Quality Limitations	2-23
11.5	Evaluation Criteria and Minimum Reporting Requirements	2-23
12.0	**TASK 4: DATA HANDLING PROTOCOL**	2-24
12.1	Introduction	2-24
12.2	Experimental Objectives	2-24
12.3	Work Plan	2-24
13.0	**TASK 5: QUALITY ASSURANCE/QUALITY CONTROL**	2-25
13.1	Introduction	2-25
13.2	Experimental Objectives	2-25
13.3	Work Plan	2-26
13.4	Daily QA/QC Checks	2-26
13.5	QA/QC Checks Performed Every Two Weeks	2-26

TABLE OF CONTENTS (continued)

Page

13.6 QA/QC Checks for Each Test Period 2-26
13.7 Analytical Methods 2-26
13.7.1 pH 2-27
13.7.2 Alkalinity 2-27
13.7.3 Temperature 2-27
13.7.4 Chloride 2-27
13.7.5 Sulfate 2-28
13.7.6 Silica 2-28
13.7.7 Hardness 2-28
13.7.8 Iron 2-28
13.7.9 Manganese 2-28
13.7.10 UV_{254} Absorbance 2-28
13.7.11 Turbidity 2-28
13.7.11.1 Bench-top Turbidimeters 2-29
13.7.11.2 In-line Turbidimeters 2-29
13.7.12 TOC 2-29
13.7.13 DBPs Samples 2-30
13.7.14 Optional Monitoring: Microbial Parameters (Total Coliforms and Heterotrophic Plate Count Bacteria) 2-30
13.8 Simulated Distribution System Test Protocol 2-30
13.8.1 Chlorine Stock Solution Preparation 2-31
13.8.2 Preparation of Additional Chemicals 2-31
13.8.3 Sample Collection and Incubation 2-31
13.8.4 Analytical Measurements 2-31

14.0 OPERATION AND MAINTENANCE 2-31
14.1 Maintenance 2-32
14.2 Operation 2-32

15.0 REFERENCES 2-35

TABLES

Table 1 Task Descriptions 2-36
Table 2 Operational Data Collection Schedule 2-37
Table 3 Water Quality Sample Schedule 2-38
Table 4 Analytical Methods 2-39

FIGURES

Figure 1 Schematic of Membrane Operational Plan 2-40

1.0 APPLICATION OF THIS VERIFICATION TESTING PLAN

This document is a Technology Specific Test Plan (TSTP) for evaluation of water treatment equipment utilizing membrane processes. This TSTP is to be used as a guide in the development of a Product Specific Test Plan (PSTP) for testing of membrane process equipment to achieve removal of precursors to disinfection by-products (DBPs). Refer to the "Protocol For Equipment Verification Testing Removal of Precursors to Disinfection By-Products: Chapter 1 General Requirements" for further information. It should be noted that this TSTP is only applicable to pressure-driven membrane processes. This TSTP is applicable to any pressure-driven membrane process used to achieve removal of precursors to DBPs.

Furthermore, this TSTP is applicable to any membrane configuration and geometries as long as it is adequately described by the manufacturer. Various membrane configurations are currently employed for water treatment applications including:

- Spiral-wound (SW);
- Hollow-fiber (HF);
- Tubular;
- Cassette;
- Cartridge; and
- Flat sheet.

To participate in the equipment verification process for membrane processes, the equipment manufacturer and its designated Field Testing Organization (FTO) shall employ the procedures and methods described in this TSTP and in the referenced Environmental Technology Verification (ETV) protocol document as guidelines for the development of a PSTP. The PSTP should generally follow those tasks outlined herein, with changes and modifications made for adaptations to specific membrane equipment. At a minimum, the format of the procedures written for each task should consist of the following sections:

- Introduction;
- Objectives;
- Work Plan;
- Analytical Schedule; and
- Evaluation Criteria.

The primary treatment goal of the equipment employed in this verification testing program is to achieve removal of DBP precursors present in water supplies such that product waters are of acceptable water quality. The experimental design of the PSTP shall therefore be developed so the relevant questions about water treatment equipment capabilities can be answered. Each PSTP shall include at a minimum Tasks 1 to 5.

2.0 INTRODUCTION

Pressure-driven membrane processes are currently in use for a broad number of water treatment applications ranging from removal of particulate matter to removal of natural organic matter

contributing to disinfection by-product formation and microbial contaminants such as *Giardia* and *Cryptosporidium*. Typically, higher pressure membrane applications such as nanofiltration (NF) and reverse osmosis (RO) are predominantly employed to achieve removal of inorganic constituents, total dissolved solids (TDS), total organic carbon (TOC), and other inorganic constituents such as salt species. Pretreatment processes ahead of NF or RO systems are generally required to remove particulate material and to ensure provision of a high quality water to the membrane systems. Typically, low pressure membrane processes, such as microfiltration (MF) and ultrafiltration (UF) are employed to provide a physical barrier for removal of microbial and particulate contaminants from source waters. However, these low pressure membrane processes have also been shown to be effective for removal of TOC and precursors to DBPs when used in conjunction with pretreatment processes.

3.0 GENERAL APPROACH

This TSTP is broken down into 7 tasks, as shown in the experimental matrix in Table 1. As noted above, these tasks shall be performed by any manufacturer wanting the performance of their equipment verified under the ETV Program. The manufacturer's designated FTO shall provide full detail of the procedures to be followed in each task in the PSTP. The FTO shall specify the operational conditions to be verified during verification testing. All permeate flux values shall be reported in terms of temperature-corrected flux values, as either gallons per square foot per day (gfd) at 68 °F or liters per square meter per hour ($L/(m^2\text{-hr})$ at 20 °C.

It should be noted that NF and RO membranes cannot be applied to surface waters without pretreatment of the feedwater to the membrane system. For surface water applications, proper pretreatment must be applied as specified by the manufacturer. In the design of the PSTP, the manufacturer shall stipulate which feedwater pretreatments are appropriate for application before the NF and RO membrane processes. The recommended pretreatment process(es) shall then be employed for feedwater pretreatment during implementation of the verification testing.

The verification testing shall be performed in one two-month testing period (not including time for system mobilization, shakedown and initial test runs). At a minimum, one, two-month period of verification testing shall be conducted.

4.0 OVERVIEW OF TASKS

The following section provides a brief overview of the required and optional tasks to be included in the membrane verification testing program.

4.1 Task A: Characterization of Feed Water

The objective of this initial operations task is to obtain a chemical and physical characterization of the feed water prior to testing.

4.2 Task B: Initial Test Runs

The objective of this initial operations task is to evaluate equipment operation and determine the treatment conditions that result in effective treatment of the feed water. This task is considered shakedown testing and shall be carried out prior to performing Tasks 1 through 5.

4.3 Task 1: Membrane Flux and Operation

The objective of this task is to evaluate membrane operation. Membrane productivity, rate of flux decline, and rejection capabilities will be evaluated in relation to feedwater quality and changes in quality resulting from seasonal or climatic changes. The impact of scale formation on membrane flux may also be evaluated via addition of different pretreatment chemicals.

4.4 Task 2: Cleaning Efficiency

An important aspect of membrane operation is the restoration of membrane productivity after flux decline has occurred. The objective of this task is to evaluate the efficiency of the membrane cleaning procedures recommended by the manufacturer. The fraction of specific flux which is restored following a chemical cleaning will be determined.

4.5 Task 3: Finished Water Quality

The objective of this task is to evaluate the quality of water produced by the membrane system. Multiple water quality parameters will be monitored during the two-month testing period. The required water quality parameters, shall include TOC, UV absorbance (at 254 nm wavelength), DBP formation potential (specific DBPs to be identified by manufacturer), TDS, conductivity, alkalinity, calcium hardness, ortho-phosphate, sulfate, chloride, bromide, silica (total & dissolved), iron, manganese, and turbidity. Other water quality parameters will be optional, such as color, heterotrophic plate count (HPC), bacteria, and individual metal ion concentrations. Water quality produced will be evaluated in relation to feedwater quality and operational conditions. Post-treatment capabilities of the equipment shall also be evaluated for removal of carbon dioxide and hydrogen sulfide from the permeate water (if present).

4.6 Task 4: Data Management

The objective of this task is to establish effective field protocol for data management at the field operations site and for data transmission between the FTO and NSF International (NSF).

4.7 Task 5: QA/QC

An important aspect of verification testing is the protocol developed for quality assurance and quality control. The objective of this task is to assure accurate measurement of operational and water quality parameters during membrane equipment verification testing.

5.0 TESTING PERIODS

The required tasks of the TSTP (Tasks 1 through 5) are designed to be completed over one (1) two-month period, not including mobilization, shakedown and initial test runs. Membrane testing conducted beyond the required two months of testing may be used for fine-tuning of membrane performance or for evaluation of additional operational conditions. During testing periods, Tasks 2 and 3 (evaluation of cleaning efficiency and finished water quality) can be performed concurrent with Task 1, the flux and operation testing procedures.

A minimum of one verification testing period shall be performed. Additional verification testing periods may be necessary to verify the manufacturer's statement of performance capabilities, such as in the treatment of surface water where additional testing during each season may assist in verifying a statement of performance capability. For systems treating solely groundwater or surface waters of consistent quality due to pre-treatment, one verification testing period may be sufficient. If one verification testing period is selected, the feed water should represent the worst-case concentrations of contaminants which can verify the manufacturer's statement of performance capabilities. For example, climatic changes between rainy and dry seasons may produce substantial variability in feedwater turbidity for surface water sources. Cold weather operations will be an important component of seasonal water quality testing because of the impact of cold temperatures (1°C to 5°C) on water viscosity and diffusional processes. In particular, for membrane process treatment equipment, factors that can influence treatment performance include:

- High concentration of natural organic matter (measured as TOC), which may be higher in some waters during different seasonal periods;
- High turbidity, often occurring in spring as a result of high runoff resulting from heavy rains or snowmelt;
- Feedwaters with high seasonal hardness and TDS concentration. These conditions may promote precipitation of inorganic materials in the membrane;
- Cold water, encountered in winter or at high altitude locations; and
- Feedwaters that may exhibit algal blooms on a seasonal basis.

It is highly unlikely that all of the above problems would occur in a water source during a single two-month period. Although one testing period satisfies the minimum requirement of ETV, manufacturers are encouraged to use additional testing periods to cover a wider range of water quality conditions.

Verification testing periods consist of continued evaluation of the treatment system using the pertinent treatment parameters defined by the manufacturer. Performance and reliability of the equipment shall be tested during verification testing periods at a minimum of two months. The purpose of the two-month test period is to demonstrate the ability of the equipment to meet the water quality goals specified by the manufacturer and to assess the product water recovery and the rate of flux decline observed during the period of operation.

6.0 DEFINITION OF OPERATIONAL PARAMETERS

Definitions that may apply to membrane processes include:

6.1 Permeate: Water produced by the NF or RO membrane filtration process.

6.2 Feedwater: Water introduced to the membrane module.

6.3 Concentrate: Concentrated solution of membrane-rejected materials retained on the feedwater side of the membrane during cross-flow membrane filtration. In a multiple-stage membrane configuration, this concentrated stream of rejected materials is passed to the subsequent stage of the membrane process array for further concentration.

6.4 Permeate Flux: The average permeate flux is the flow of permeate water divided by the surface area of the membrane. Permeate flux is calculated according to the following formula:

$$J_t = \frac{Q_p}{S}$$

where: J_t = permeate flux at time t (gfd, L/(h-m^2))
Q_p = permeate flow (gpd, L/h)
S = membrane surface area (ft^2, m^2)

It should be noted that only gfd and L/(h-m^2) shall only be used as units of flux.

6.5 Specific Flux: The term specific flux is used to refer to permeate flux that has been normalized for the transmembrane pressure. The equation used for calculation of specific flux is given as follows:

$$J_{tm} = \frac{J_t}{P_{tm} - \Delta\pi}$$

where J_{tm} = specific flux at time t (gfd/psi, L/(h-m^2)/bar)
J_t = permeate flux at time t (gfd, L/(h-m^2))
P_{tm} = transmembrane pressure (psi, bar)
$\Delta\pi$ = osmotic pressure (psi, bar)

Specific flux results shall always be reported with indication of the time interval after initiation of the experimental test run.

6.6 Membrane Fouling: A reduction in permeate flux that can be restored by mechanical or chemical means is termed “reversible” fouling. In contrast, “irreversible fouling” is defined as a permanent loss in permeate flux capacity that cannot be restored.

6.7 Transmembrane Pressure: The average transmembrane pressure is calculated:

$$P_{tm} = \left[\frac{(P_i + P_o)}{2} - \Delta\pi \right] - P_p$$

where P_{tm} = transmembrane pressure (psi, bar)
P_i = pressure at the inlet of the membrane module (psi, bar)
P_o = pressure at the outlet of the membrane module (psi, bar)
$\Delta\pi$ = osmotic pressure (psi, bar)
P_p = permeate pressure (psi, bar)

6.8 Temperature Adjustment for Flux Calculation: Temperature corrections to 20°C for transmembrane flux shall be made to correct for the variation of water viscosity with temperature (Streeter and Wiley, 1985). A specific, empirically-derived equation developed by the membrane manufacturer may be used to provide temperature corrections for specific flux calculations, or the following equation by Streeter and Wiley (1985) may be employed:

$$J_t(\text{at } 20^{\circ}\text{C}) = \frac{Q_p \times e^{-0.0239 \times (T-20)}}{S}$$

where J_t = instantaneous flux (gfd, L/(h-m^2))
Q_p = permeate flow (gpd, L/h)
T = temperature, (°C)
S = membrane surface area (ft^2, m^2)

6.9 Feedwater System Recovery: The total recovery of permeate from feedwater is given as the ratio of total permeate flow to feedwater flow:

$$\%\ \text{System Recovery} = 100\left[\frac{Q_p}{Q_f}\right]$$

where Q_p = permeate flow (gpd, L/h)
Q_f = feed flow to the membrane (gpd, L/h)

6.10 Membrane Process Recovery: The recovery of permeate from total recirculation influent water is given as the ratio of permeate flow to the sum of feedwater flow and recycle flow:

$$\%\ \text{Element Recovery} = 100\left[\frac{Q_p}{Q_f + Q_r}\right]$$

where Q_p = permeate flow (gpd, L/h)

Q_f = feed flow to the membrane (gpd, L/h)
Q_r = recycle flow (gpd, L/h)

6.11 Foulants: Plugging or deposition or bonding of dissolved/suspended matter on the membrane surface. It typically occurs at the front end of each pressure vessel when the feed enters the membrane.

6.12 Scaling: The precipitation of sparingly soluble salts within the feed side of the membrane. It typically occurs at the end of each pressure vessel where concentration is greatest.

7.0 TASK A: CHARACTERIZATION OF FEED WATER

This initial operations task is needed to determine if the chemical and physical characteristics of the feed water are appropriate for the water treatment equipment to be tested.

7.1 Objectives

The objective of this task is to obtain a complete chemical and physical characterization of the feed water that will be entering the treatment system being tested.

7.2 Work Plan

This task can be accomplished by using analytical measurements obtained from third party sources (i.e. USGS, EPA, state laboratories, municipal laboratories). The specific parameters needed to characterize the water will depend on the equipment being tested but information on the following characteristics should be compiled:

- Temperature, pH, turbidity, and UV_{254} absorbance;
- Total alkalinity, conductivity, total hardness, dissolved iron, and dissolved manganese;
- TOC, TDS;
- Sulfate, chloride, bromide, silica (total and dissolved); and
- Apparent molecular weight size distribution (optional, but recommended).

If sufficient historic data is not available to properly evaluate the feed water quality, additional monitoring of the feed water should be performed to adequately assess feed water quality. Ideally, one year of historic water quality data for each parameter will be available for the proposed feed water. At a minimum, one month of data, sampled at no greater than weekly intervals, may constitute historic data.

Sufficient information shall be obtained to illustrate the variations expected to occur in these parameters that will be measured during verification testing for the water source. This information will be compiled and shared with NSF so NSF and the testing organization can determine the adequacy of the data for use as the basis to make decisions on the testing schedule. Failure to adequately characterize the feed water could result in testing at a site later deemed

inappropriate, so the initial characterization will be important to the success of the testing program.

7.3 Analytical Schedule

In many cases, sufficient water quality data may already exist to permit making a determination of the suitability of a source water for use as feed water in a membrane verification testing program. If sufficient historic data is not available to properly evaluate the source water quality, additional monitoring of the source water shall be performed to adequately assess source water quality.

Analyses for apparent molecular weight size distribution, an optional but recommended parameter for characterizing the natural organic matter (NOM) in the feed water, are non-standard but may be used if the methods have undergone peer review. Suggested references include Logan and Jiang (1990) and studies by the American Water Works Association Research Foundation (AWWARF). Methods chosen for NOM analyses must be stated in the PSTP and reviewed by NSF prior to testing. Data generated from NOM analyses may be helpful in assisting the manufacturer in the selection of the type of membrane that is suitable for treating the feed water.

7.4 Evaluation Criteria

Feed water quality will be evaluated in the context of the manufacturer's statement of performance capabilities. The feed water should challenge the capabilities of the equipment but should not be beyond the range of water quality suitable for treatment for the equipment in question.

8.0 TASK B: INITIAL TEST RUNS

8.1 Introduction

During initial test runs, the equipment shall be operated to evaluate and determine the treatment conditions that result in effective treatment of the feed water.

8.2 Objectives

The objective of this initial operations task is to evaluate equipment operation and determine the treatment conditions that result in effective treatment of the feed water.

8.3 Work Plan

Initial test runs shall be conducted so a preliminary assessment of treatment performance can be made, especially for filtered water DBP precursors. If more than one verification test period is planned, this task shall occur prior to each test period. This task is considered shakedown testing and shall be carried out prior to performing Tasks 1 through 5.

8.4 Analytical Schedule

Because these runs are being conducted to determine the suitability of the technology for verification testing, a strictly defined schedule for sampling and analysis does not need to be followed. Adhering to the schedule for sampling and analysis to be followed during verification testing would be wise so the operator can gain familiarity with the time requirements that will be applicable later on in the test program.

8.5 Evaluation Criteria

The manufacturer should evaluate the data produced during the initial test runs to determine if the water treatment equipment performance met or exceeded expectations based on the statement of performance capabilities. If the performance was not as good as the statement of performance capabilities, the manufacturer may wish to conduct more initial test runs or to cancel the testing program.

9.0 TASK 1: MEMBRANE FLUX AND OPERATION

9.1 Introduction

Membrane operation will be evaluated in this task, with quantification of membrane flux decline rates and permeate water recoveries. The rates of flux decline will be used to demonstrate membrane performance at the specific operating conditions to be verified. The operational conditions to be verified shall be specified by the FTO in terms of a temperature-corrected flux value (e.g., gfd at 68 °F or L/(m^2-hr) at 20 °C) before the initiation of the verification testing program.

Rate of flux decline is a function of water quality and operational strategy. Many additional factors may influence specific flux decline with high-pressure membranes such as NF and RO including membrane compaction, membrane ripening, inorganic scaling, particulate or organic fouling, biofouling, and other factors. In this task, specific flux decline and water quality shall be monitored to evaluate operational trends and membrane rejection capabilities. Flowrate, pressure, and temperature data shall be collected to quantify the rate of specific flux decline. A lower rate of specific flux decline implies that a longer operational run will be achieved by the membrane system.

Some manufacturers may wish to employ a low pressure membrane system preceded by an organics removal pretreatment process (such as pretreatment addition of a coagulant or adsorbent prior to membrane filtration) to achieve removal of precursors to DBPs. Any pretreatment included in the membrane treatment system that is designed for removal of precursors to DBPs shall be considered an integral part of the membrane treatment system and shall not be tested independently. In such cases, the system shall be considered as a single unit and the pretreatment process shall not be separated for optional evaluation purposes.

Before the initiation of verification testing, the manufacturer shall make known the limitations of the equipment and any existing equipment incompatibilities with treatment processes or chemical additions. To this end, a listing shall be provided by the manufacturer describing the potentially incompatible treatment processes or chemical additions (i.e., oxidants, coagulants, anti-scalants) that would adversely impact the equipment materials or the treatment process. In addition, the FTO shall report any incompatibilities between equipment and treatment processes or chemical additions that are observed during the course of the verification testing program.

9.2 Experimental Objectives

The objectives of this task are to demonstrate 1) the appropriate operational conditions for the membrane equipment; 2) the permeate water recovery achieved by the membrane equipment; and 3) the rate of flux decline observed over extended membrane filtration operation. Raw water quality shall be monitored (Task 3) during the two-month testing period to track any variations in water quality that could impact fouling rates. The potential for significant variation in raw water quality applies primarily to surface waters.

It should be noted that the objective of this task is not process optimization, but rather verification of membrane operation at the operating conditions specified by the FTO, as pertains to permeate flux and transmembrane pressure. Verification of membrane operation shall also apply to operating conditions that are considered less stringent than those conditions tested; examples would include lower permeate fluxes and higher cross-flow velocities.

9.3 Work Plan

Determination of optimal membrane operating conditions for a particular water can typically require as long as one year of operation. For this task, the FTO shall specify the operating conditions to be evaluated in the PSTP and shall supply written procedures on the operation and maintenance of the membrane treatment system. The FTO shall also specify the membrane run termination criteria for the particular membrane equipment. For example, the termination criteria may be defined as a 20 percent decline in specific flux, or increase in transmembrane pressure to a specific value. In this task, each set of operating conditions shall be maintained for a two-month testing period (continuous 24-hour operation). Because only one testing period shall be required (two-months) in this TSTP, the FTO shall specify the primary permeate flux at which the equipment is to be verified.

After set-up and shakedown of membrane equipment, membrane operation should be established at the flux condition to be verified. The membrane system shall be operated as shown schematically in Figure 1 for a minimum of two months. If substantial specific flux decline occurs under this specified flux condition before the two-month operating period is complete, adjustments to the operational strategy shall be made (such as a decrease in flux or recovery). Decisions on adjustments shall be made based upon the manufacturer's experience and consultation with the FTO conducting the study. At a minimum, the membrane shall be chemically cleaned according to manufacturer's specifications at the conclusion of the two-month period. At this time, the cleaning efficiency shall be determined per Task 2.

This TSTP has been written with the aim to balance the costs of verification with the benefits of testing membrane filtration over a wide range of operating conditions. Given that it may take one month longer to observe significant flux decline in a high-pressure membrane system, examination under a wide range of operating conditions would be prohibitively expensive for the membrane manufacturer. Therefore, this TSTP requires that one set of operating conditions be tested for the one two-month period. It shall be understood that beyond the single set of verification operating conditions, membrane operation that occurs at a lower flux, a lower recovery, or a higher cross-flow velocity shall also constitute a verifiable condition.

To establish appropriate conditions of flux, recovery, backwash frequency and duration the manufacturer may have some experience with his equipment on a similar water source. This may not be the case for suppliers with new products. In this case, it is advisable to require a pre-test optimization period so that reasonable operating criteria can be established. This would aid in preventing the unintentional but unavoidable optimization during the verification testing. The need of pre-test optimization should be carefully addressed with NSF, the FTO and the manufacturer early in the process.

Testing of additional operational conditions may be included in the verification testing program at the discretion of the manufacturer and its designated FTO. Testing of alternate operational conditions shall be performed by including additional two-month testing periods. Operation of the membrane equipment during the optional testing periods shall be supervised by the FTO or by a separate entity, as determined by previous agreement between the manufacturer and the FTO.

Additional months of testing may also be included in the PSTP to demonstrate membrane performance under different feedwater quality conditions. For membrane filtration, extremes of feedwater quality (e.g., low temperature, high TOC concentration, high TDS, high turbidity) are the conditions under which membranes are most prone to rapid flux decline and to failure. The FTO shall perform testing with as many different water quality conditions as desired for verification status. Testing under each different water quality condition shall be performed during an additional two-month testing period, as required above for each additional set of operating conditions.

The testing runs conducted under this task shall be performed in conjunction with Tasks 2 and 3. With the exception of the additional testing periods conducted at the FTO's discretion, no additional membrane test runs are required for performance of Tasks 2 and 3.

9.4 Analytical Schedule

9.4.1 Operational Data Collection

Measurement of membrane feedwater flow and permeate flow (recycle flow where applicable) and system pressures shall be collected at a minimum of 2 times per day. Temperatures (feedwater, permeate, recirculation water, concentrate) shall be collected at a minimum once daily. Table 2 presents the operational data collection schedule.

Temperature measurements shall be made to provide data for correction of transmembrane flux.

In an attempt to assess cost factors for operation of membrane equipment, power for operation of the membrane equipment shall also be closely monitored and recorded by the FTO during the two-month testing period. Power usage shall be quantified by the following measurements: pumping requirements, size of pumps, nameplate voltage, current draw, power factor. Chemical usage shall be quantified by recording day tank concentration and daily volume consumption. No additional operational data shall be required by Tasks 2 through 4 unless specifically stated.

9.4.2 Feedwater Quality Limitations

The characteristics of feedwaters used during the two-month testing period (and any additional testing periods) shall be explicitly stated in reporting the membrane flux and recovery data. Accurate reporting of such feedwater characteristics as temperature, TOC concentration, UV_{254} absorbance, TDS, conductivity, alkalinity, calcium hardness, ortho-phosphate, sulfate, chloride, bromide, iron, manganese, silica, turbidity, and pH is critical for the verification testing program, as these parameters may substantially influence the range of achievable membrane performance and treated water quality under variable raw water quality conditions.

9.4.3 Waste Stream Water Quality

The waste streams from the treatment process equipment shall be characterized by measurement of the following water quality parameters: pH, TDS, TOC, coliform bacteria, as indicated in Table 3. Quantification shall also be provided of the rates of consumption of chemicals and rates of waste production. The specific waste stream flows from routine cleaning, chemical cleaning and other cleaning processes shall be quantified individually.

9.5 Evaluation Criteria and Minimum Reporting Requirements

The minimum reporting requirements shall include presentation of the following results:

- Rate of specific flux decline:
  - Plot graph of specific flux normalized to 20°C over time for each 60 day period of operation.
- Cleaning efficiency:
  - Provide table of intervals between chemical cleaning episodes and efficiency of cleaning following the two-month period of operation.

- Waste stream water quality:
  - Provide table of waste stream concentrations of any measured water quality parameters for each 60 day period of operation.

- Report of equipment incompatibilities:
  - Provide report of any observed incompatibilities between equipment and treatment processes or chemical additions.

10.0 TASK 2: CLEANING EFFICIENCY

10.1 Introduction

Following the test runs of Task 1, the membrane equipment may require chemical cleaning to restore membrane productivity. At a minimum, one cleaning shall be performed at the conclusion of the two-month period of required testing. In the case where the membrane does not fully reach the operational criteria for termination as specified by the manufacturer and its designated FTO in Task 1, chemical cleaning shall be performed after the 60 days of operation, with a record made of the operational conditions before and after cleaning.

10.2 Experimental Objectives

The objective of this task is to evaluate the effectiveness of chemical cleaning for restoring specific flux of the membrane systems. The intent of this task is to confirm that standard manufacturer-recommended cleaning practices are sufficient to restore membrane productivity and do not degrade the membrane in terms of organics rejection capabilities for the systems under consideration. Cleaning chemicals and cleaning routines shall be based on the recommendations of the manufacturer; this task is considered a "proof of concept" effort, not an optimization effort. It should be noted that cleaning solution selection is typically feedwater quality specific. The PSTP should permit evaluation of cleaning solutions that are considered optimal for water being treated. If the manufacturer determines that a pre-selected cleaning formulation is not effective, the PSTP should allow the manufacturer to modify it.

10.3 Work Plan

The membrane systems may experience specific flux decline during the membrane test runs conducted for Task 1. At the conclusion of the two-month testing period, these membranes shall be utilized for the cleaning assessments herein. No additional experiments shall be required to produce specific flux decline such that chemical cleaning evaluations be performed. Each system shall be chemically cleaned using the recommended cleaning solutions and procedures specified by the manufacturer. After each chemical cleaning of the membranes, the system shall be restarted and the initial conditions of specific flux recovery and organics rejection capabilities shall be tested.

The manufacturer and its designated FTO shall specify in detail in the PSTP the procedure(s) for chemical cleaning of the membranes. At a minimum, the following shall be specified:

- Cleaning chemicals;
- Quantities of cleaning chemicals;
- Hydraulic conditions of cleaning;

- Duration of each cleaning step;
- Initial and final temperatures of chemical cleaning solution;
- Quantity and characteristics of residual waste volume to be disposed; and
- Recommended methods and considerations for disposal of residual cleaning waste.

In addition, detailed procedures describing the methods for pH neutralization of the acid or alkaline cleaning solutions should be provided along with information on the proper disposal method for regulated chemicals. A description of all cleaning equipment and its operation shall be included in the PSTP prepared by the FTO.

10.4 Analytical Schedule

10.4.1 Sampling

The pH, conductivity, TDS, and turbidity of each cleaning solution shall be measured and recorded during various periods of the chemical cleaning procedure. In addition, in the case that the cleaning solution employs an oxidant, such as chlorine, the concentration of the oxidant both before and at the end of the cleaning should be measured. Notes recording the visual observations (color, degree of suspended matter present) shall also be provided by the FTO. No other water quality sampling shall be required.

10.4.2 Operational Data Collection

Flow, pressure, recovery, and temperature data shall be collected during the cleaning procedure if possible and shall be recorded immediately preceding system shutdown. At the conclusion of each chemical cleaning event and immediately upon return to membrane operation, the initial condition of transmembrane pressure, recovery, and temperature shall be recorded and the specific flux calculated.

10.5 Evaluation Criteria and Minimum Reporting Requirements

The efficacy of chemical cleaning shall be evaluated by the recovery of specific flux after chemical cleaning as noted below, with comparison drawn from the cleaning efficacy achieved during previous cleaning evaluations. Comparison between chemical cleanings shall allow evaluation of the potential for irreversible loss of specific flux and projections for usable membrane life. Analysis of feedwater and permeate water quality in subsequent runs shall also be used to evaluate any loss in membrane rejection capabilities caused by chemical cleaning.
Two primary indicators of cleaning efficiency and restoration of membrane productivity will be examined in this task:

1. The immediate recovery of membrane productivity, as expressed by the ratio between the final specific flux value of the current filtration run (Js_f) and the initial specific flux (Js_i) measured for the subsequent filtration run:

$$\% \text{ Recovery of Specific Flux} = 100\left[1 - \frac{Js_f}{Js_i}\right]$$

where: Js_f = Specific flux (gfd/psi, L/(h-m2)/bar) at end of current run (final); and
Js_i = Specific flux (gfd/psi, L/(h-m2)/bar) at beginning of subsequent run (initial).

2. The loss of specific flux capabilities, as expressed by the ratio between the initial specific flux for any given filtration run (Js_i) divided by the specific flux (Js_{io}) at time zero, as measured at the initiation of the first filtration run in a series:

$$\% \text{ Loss of Original Specific Flux} = 100\left[1 - \frac{Js_i}{Js_{io}}\right]$$

where: Js_{io} = Specific flux (gfd/psi, L/(h-m2)/bar) at time zero point of membrane testing.

The minimum reporting requirements shall include presentation of the following results:

- Flux recovery:
  - Provide table of post cleaning flux recoveries during each 60 day period of operation.

- Cleaning efficacy:
  - Provide table of cleaning efficacy indicators described above for chemical cleaning procedures performed during each 60 day period of operation.

- Assessment of irreversible loss of specific flux and estimation of usable membrane life for costing purposes.

11.0 TASK 3: FINISHED WATER QUALITY

11.1 Introduction

Water quality data shall be collected for the feedwater and membrane permeate water as shown in the sampling schedule Table 3, during the membrane test runs of Task 1. At a minimum, the required sampling schedule shown in Table 3 shall be observed by the FTO on behalf of the manufacturer. Water quality goals and target removal goals for the membrane equipment shall be recorded in the PSTP.

11.2 Experimental Objectives

The objective of this task is to assess the ability of the membrane equipment to demonstrate the stated rejection capabilities and meet the water quality goals specified by the manufacturer. A list of the minimum number of water quality parameters to be monitored during equipment verification testing is provided in the analytical schedule section below and in Table 3. The

actual water quality parameters selected for testing and monitoring shall be stipulated by the FTO in the PSTP.

11.3 Work Plan

The manufacturer through its designated FTO shall identify the DBP precursor rejection capabilities in the statement of performance capabilities provided in the PSTP. The manufacturer's performance objective(s) is used to establish data quality objectives (DQOs) to develop the experimental design of the verification test. The broader the performance objective(s), the more comprehensive the PSTP must become to achieve the DQOs. In the statement of performance capabilities, the manufacturer shall identify the specific DBPs that shall be monitored during equipment testing. The statement of performance capabilities prepared by the manufacturer and its designated FTO shall also indicate the range of water quality under which the equipment can be challenged while successfully treating the feedwater. Two examples of satisfactory statements of performance capabilities are provided below:

1. "This system is capable of achieving 90 percent removal of dissolved organic carbon (DOC) in feedwaters with TOC concentrations between 2.0 and 4.0 mg/L and with feedwater alkalinities less than 60 mg/L as $CaCO_3$."

2. "This system is capable of achieving 90 percent removal of precursors to trihalomethanes (THMs) and haloacetic acids (HAAs) in feedwaters. Removal of THM and HAA precursors will be quantified by comparison of simulated distribution system (SDS) testing results (Uniform Formation Conditions (UFC) under the Information Collection Rule (ICR)) generated for feed and finished water samples."

It should be noted that many of the drinking water treatment systems participating in the DBP precursor removal verification testing program will be capable of achieving multiple water treatment objectives. Although this DBP precursor protocol and the associated TSTP are oriented towards removal of DBP precursors, the manufacturer may want to look at the treatment system's removal capabilities for additional water quality parameters. Furthermore, in light of the fact that the treatment process may alter water quality beyond a simple reduction of precursors to disinfection by-products, the FTO shall also report and discuss the potential impacts that the treatment process may have on other pertinent water quality characteristics such as pH, hardness, alkalinity, corrosivity, LSI, etc. For example, a treatment process such as RO may reduce hardness and alkalinity, increasing the corrosivity of treated waters such that actual systems employing the equipment might have problems meeting lead and copper standards in certain distribution systems.

Many of the water quality parameters described in this task shall be measured on-site by the FTO (refer to Table 4). Analysis of the remaining water quality parameters shall be performed by a laboratory that is certified, accredited or approved by a state, a third-party organization (i.e., NSF), or the EPA. The methods to be used for measurement of water quality parameters in the field are described in the analytical methods section below and in Table 4. The analytical methods utilized in this study for on-site monitoring of feedwater and permeate water qualities are described in Task 5, Quality Assurance/ Quality Control (QA/QC). Where appropriate, the

Standard Methods reference numbers and EPA method numbers for water quality parameters are provided for both the field and laboratory analytical procedures.

For the water quality parameters requiring analysis at a laboratory, water samples shall be collected in appropriate containers (containing necessary preservatives as applicable) prepared by the accredited laboratory that is certified. These samples shall be preserved, stored, shipped, and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical lab.

11.4 Analytical Schedule

11.4.1 Removal of Simulated Distribution System Precursors to DBPs

During the steady-state operation of each membrane testing period, SDS DBP testing shall be performed on the membrane feedwater and the permeate water to determine the precursor removal capabilities of the membrane system. SDS DBP testing shall be used to determine removal of any disinfection by-products (e.g., THMs, HAAs, haloketones, etc.) identified by the FTO in the PSTP.

For evaluation of the DBP precursor concentrations, the FTO will be permitted to conduct SDS testing at the standard disinfectant conditions of the distribution system of the utility participating in the verification testing program. In the case that no utility-specific SDS conditions are identified, the FTO shall employ the standardized ICR approach of the UFC in this verification testing program. This SDS method shall be performed by spiking a water sample with a disinfectant and holding the sample in the dark at the UFC specified in the ICR Manual for Bench- and Pilot-Scale Treatment Studies. (Refer to the SDS test protocol in the QA/QC section of this TSTP for further details.) The following UFC may thus be used for DBP formation testing:

- Incubation time: 24 +/- 1 hours
- Incubation temperature: 20.0 +/- 1.0 °C
- Buffered pH: 8.0 +/- 0.2
- 24-hour Chlorine Residual: 1.0 +/- 0.4 mg Cl_2/L

For these conditions, the chlorine dose required to achieve the target chlorine residual can be determined by first conducting a demand study with the water sample. Since the DOC concentrations of a water can vary over the course of a test run, the chlorine demand of a given water may also vary. The chlorine dose must therefore be varied according to the chlorine demand of the water. Frequency of sampling and SDS DBP analysis shall be specified by the individual TSTPs used for the verification testing and shall also be stipulated in the PSTP.

In the case that this verification testing program is performed in conjunction with utility operation, the SDS DBP formation conditions employed for this test plan may be tailored to correspond to the appropriate SDS conditions at the corresponding utility.

11.4.2 Feed and Permeate Water Characterization

At the beginning of the membrane testing period (and thereafter with indicated frequency), the raw water and permeate water shall be characterized at a single set of operating conditions by measurement of the following water quality parameters (as indicated in Table 3):

- Alkalinity (twice per month);
- Total and calcium hardness (twice per month);
- TDS (twice per month);
- Conductivity (twice per month);
- Ortho-phosphate (twice per month);
- Sulfate (twice per month);
- Chloride (twice per month);
- Bromide (twice per month);
- Dissolved iron and dissolved manganese (twice per month);
- Silica (total & dissolved) (twice per month);
- Silt Density Index (SDI) of feedwater to high pressure membrane system (twice per month);
- Total suspended solids (twice per month);
- TOC(twice per week);
- Color or UV_{254} absorbance (daily), UV_{254} shall be collected at least once weekly;
- Temperature (daily);
- pH (daily);
- Permeate water turbidity (daily);
- Feed (and concentrate) water turbidity (daily);
- Total coliform (TC) and HPC bacteria (optional testing);
- THM concentrations from SDS testing (minimum of eight samples over the duration of the test);
- HAA concentration from SDS testing (minimum of eight samples over the duration of the test);
- Any additional DBP compounds formed during SDS testing (minimum of eight samples over the duration of the test). DBP species to be monitored shall be specified by FTO in the PSTP. Some additional, optional DBPs may include:
  - chloral hydrate
  - chloropicrin
  - haloketones; and
  - haloacetonitriles.

11.4.3 Water Quality Sample Collection

Water quality data shall be collected at regular intervals during the period of membrane testing. The minimum monitoring frequency for the required water quality parameters is provided in Table 3. At the discretion of the manufacturer and the designated FTO, the water quality sampling program may be expanded to include a greater number of water

quality parameters and to require a greater frequency of parameter sampling. Sample collection frequency and protocol shall be defined explicitly by the FTO in the PSTP; however, to the extent possible, analyses for organic water quality parameters shall be performed on water sample aliquots that were obtained simultaneously from the same sampling location, to ensure the maximum degree of comparability between water quality analytes.

No monitoring of microbial populations shall be required in this TSTP. However, the manufacturer may include optional monitoring of indigenous microbial populations to demonstrate removal capabilities.

Further, microbial removal through seeding studies may be evaluated during the two-month testing period. Refer to Task 8 of Chapter 2 in the "EPA/NSF ETV Protocol for Equipment Verification Testing for Physical Removal of Microbiological and Particulate Contaminants" for the details of conducting such tests.

11.4.4 Feedwater Quality Limitations

The characteristics of feedwaters encountered during the two-month testing period shall be explicitly reported with the compiled results from membrane flux and product water recovery monitoring. Accurate reporting of such feedwater characteristics as temperature, TOC concentration, UV_{254} absorbance, turbidity, TDS, pH, alkalinity, and hardness, conductivity, phosphate, and sulfate is critical for the verification testing program, as these parameters can substantially influence membrane performance on a seasonal basis.

11.5 Evaluation Criteria and Minimum Reporting Requirements

The minimum reporting requirements shall include presentation of the following results:

- Report the removal of TOC concentration, UV_{254} absorbance, SDS DBP concentrations:
  - Plot graph of percent removal across the membrane at weekly intervals over each 60-day period of operation for the following water quality parameters: TOC concentration, UV_{254} absorbance, SDS THMs, SDS HAAs, other DBPs stipulated by the manufacturer. The following equation shall be used to determine percent removal of all organic water quality parameters including TOC, UV_{254} absorbance, and precursors to DBPs:

    $$\% \text{ removal organic materials} = 100\left(1 - \frac{(\text{permeate water concentration})}{(\text{feed water concentration})}\right)$$

  - Provide feed and permeate levels for TOC, UV_{254} absorbance and monitored DBPs in tabular form for each 60 day period of operation.

- Report the turbidity and total suspended solids concentrations:
  - Plot graph of daily feed and permeate turbidity measurements during each 60 day period of operation; and

- Plot graph of daily feed and permeate total suspended solids measurements during each 60-day period of operation.

- Report the water quality and removal goals specified by the manufacturer:
  - Provide feed and permeate concentrations of any measured water quality parameters in tabular form for each 60 day period of operation.

- Report the results of optional task involving removal of indigenous bacteria (TC and HPC):
  - Provide feed and permeate levels for TC and HPC bacteria in tabular form for each 60 day period of operation; and
  - Provide values for TC and HPC log removal in tabular form for each 60 day period of operation.

- Report the results of the impacts of treatment on pertinent water quality parameters:
  - Provide information on impacts of treatment on pertinent water quality parameters not related to DBP precursor removal.

12.0 TASK 4: DATA HANDLING PROTOCOL

12.1 Introduction

The data management system used in the verification testing program shall involve the use of computer spreadsheets and manual recording of operational parameters for the membrane equipment on a daily basis.

12.2 Experimental Objectives

The objective of this task is to establish a viable structure for the recording and transmission of field testing data such that the FTO provides sufficient and reliable operational data for the NSF for verification purposes.

12.3 Work Plan

The following procedures have been developed for data handling and data verification by the FTO. Where possible, a Supervisory Control and Data Acquisition (SCADA) system should be used for automatic entry of testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters should then be downloaded by manual importation into Excel (or similar spreadsheet software) as a comma delimited file. These specific database parcels shall be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data shall be manipulated into a convenient framework to allow analysis of membrane equipment operation. At a minimum, backup of the computer databases to diskette should be performed on a monthly basis.

In the case when a SCADA system is not available, field testing operators shall record data and calculations by hand in laboratory notebooks. (Daily measurements shall be recorded on specially prepared data log sheets as appropriate.) The laboratory notebook shall provide carbon copies of each page. The original notebooks shall be stored on-site; the carbon copy sheets shall be forwarded to the project engineer of the FTO at least once per week during each two-month testing period. This protocol will not only ease referencing the original data, but offer protection of the original record of results. Operating logs shall include a description of the membrane equipment (description of test runs, names of visitors, description of any problems or issues, etc.); such descriptions shall be provided in addition to experimental calculations and other items.

The database for the project shall be set up in the form of custom-designed spreadsheets. The spreadsheets shall be capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the laboratory notebooks and data log sheets shall be entered into the appropriate spreadsheet. Data entry shall be conducted on-site by the designated field testing operators. All recorded calculations shall also be checked at this time. Following data entry, the spreadsheet shall be printed out and the print-out shall be checked against the handwritten data sheet. Any corrections shall be noted on the hard-copies and corrected on the screen, and then a corrected version of the spreadsheet shall be printed out. Each step of the verification process shall be initialed by the field testing operator or engineer performing the entry or verification step.

Each experiment (e.g. each membrane test run) shall be assigned a run number which will then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to accredited laboratories, the data shall be tracked by use of the same system of run numbers. Data from the outside laboratories shall be received and reviewed by the field testing operator. These data shall be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

13.0 TASK 5: QUALITY ASSURANCE/QUALITY CONTROL

13.1 Introduction

QA/QC of the operation of the membrane equipment, instrumentation, and the measured water quality parameters shall be maintained during the verification test.

13.2 Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures. When specific items of equipment or instruments are used, the objective is to maintain the operation of the equipment or instructions within the ranges specified by the manufacturer or by *Standard Methods*. Maintenance of strict QA/QC procedures is important, in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to determine exact conditions at the time of testing.

13.3 Work Plan

When developing the Quality Assurance Project Plan (QAPP) and the PSTP, the FTO should refer to Chapter 1, Section 6.0 Quality Assurance Project Plan in addition to the information provided herein. All of the requirements and guidelines described in Chapter 1 shall be included in the development of the PSTP. In addition to the general ETV Program QA/QC described in Chapter 1, the PSTP shall incorporate the specific membrane QA items detailed in this section.

Equipment flowrates and associated signals should be checked and recorded on a routine basis. A routine daily walk through during testing shall be established to confirm that each piece of equipment or instrumentation is operating properly. Particular care shall be taken to confirm that any chemicals are being fed at the defined flowrate into a flowstream that is operating at the expected flowrate, such that the chemical concentrations are correct. In-line monitoring equipment such as flowmeters, etc. shall be checked to confirm that the readout matches with the actual measurement (i.e. flowrate) and that the signal being recorded is correct. The items listed are in addition to any specified checks outlined in the analytical methods.

13.4 Daily QA/QC Checks:

- Chemical feed pump flowrates (checked volumetrically over a specific time period);
- In-line turbidimeter flowrates (checked volumetrically over a specific period of time to confirm instrument readings, if employed); and
- In-line turbidimeter readings checked against a properly calibrated bench-top model.

13.5 QA/QC Checks Performed Every Two Weeks

- In-line flowmeters/rotameters (check flow volumetrically over a specific period of time to confirm instrument readings and if necessary, clean equipment to remove any debris or biological buildup).

13.6 QA/QC Checks for Each Testing Period

- In-line turbidimeters (clean out reservoirs, if necessary, and recalibrate);
- Differential pressure transmitters (check gauge readings and electrical signal using a pressure meter); and
- Tubing (check condition of all tubing and connections, replace if necessary).

13.7 Analytical Methods

The analytical methods utilized in this study for on-site monitoring of feedwater and permeate water quality are described in the section below. If new methods are published and approved or current methods updated, the most current methods shall be used. Use of either bench-top or in-line field analytical equipment will be acceptable for the verification testing; however, in-line equipment is recommended for ease of operation. Use of in-line equipment is also preferable because it reduces the introduction of error and the variability of analytical results generated by inconsistent sampling techniques.

Temperature, pH, alkalinity, and turbidity must be analyzed on-site immediately after sample collection. Other parameters, such as calcium, magnesium, and hardness can be performed either on-site or in the laboratory, as long as the holding time requirements are met.

All other analyses shall be performed in a state certified or third party or EPA accredited drinking water laboratory. All samples collected for laboratory analysis, including arsenic chloride, sulfate, silica, aluminum, sodium, iron, manganese and additional parameters, shall be collected and preserved in accordance with *Standard Method* 3010 B, paying particular attention to the sources of contamination as outlined in *Standard Method* 3010 C. The samples should be refrigerated at approximately 2 to 8°C immediately upon collection, shipped in a cooler, and maintained at a temperature of approximately 2 to 8°C. Samples shall be processed for analysis within EPA approved holding times, which must be included in the PSTP. The laboratory shall keep the samples at approximately 2 to 8°C until initiation of analysis.

13.7.1 pH

Analyses for pH shall be performed according to *Standard Method* 4500-H^+ B or EPA Methods 150.1 and 150.2. A three-point calibration of the pH meter used in this study shall be performed once per day when the instrument is in use. Certified pH buffers in the expected range shall be used. The pH probe shall be stored in the appropriate solution defined in the instrument manual. Transport of carbon dioxide across the air-water interface can confound pH measurement in poorly buffered waters. If this is a problem, measurement of pH in a confined vessel is recommended to minimize the effects of carbon dioxide loss with the atmosphere.

13.7.2 Alkalinity

Analyses for alkalinity shall be performed on-site according to *Standard Method* 2320 B (Titration Method).

13.7.3 Temperature

Readings for temperature shall be conducted in accordance with *Standard Method* 2550. The thermometer shall have a scale marked for every 0.1 ^oC, as a minimum, and should be calibrated weekly against a precision thermometer certified by the National Institute of Standards and Technology (NIST). (A thermometer having a range of -1^oC to $+51^oC$, subdivided in 0.1^o increments, would be appropriate for this work.)

13.7.4 Chloride

Analyses for chloride shall be performed in the lab according to *Standard Method* 4110 B, 4500-Cl- B (Argentometric Method) or 4500-Cl- D (Mercuric Nitrate Method) or EPA Method 300.0.

13.7.5 Sulfate

Analyses for sulfate shall be performed in the lab according to *Standard Methods* 4110 B, 4500 SO4 2-C, 4500 SO4 2-D, 4500 SO4 2-E (Turbidimetric Method), or 4500 SO4 2-F, or EPA Methods 300.0 or 375.2.

13.7.6 Silica

Analyses for silica shall be performed in the lab according to *Standard Method* 3120 B, 4500-Si C, 4500-Si D (Molybdosilicate Method), or 4500-Si E, or EPA Method 200.7.

13.7.7 Hardness

Analyses for total hardness shall be performed on-site or in the lab according to *Standard Method* 2340 C (EDTA Titrimetric Method). Calcium hardness analyses shall be performed according to *Standard Method* 3500-Ca D.

13.7.8 Iron

Analyses for iron shall be performed in the lab using *Standard Method* 3120 B or EPA Methods 200.7, 200.9.

13.7.9 Manganese

Analyses for manganese shall be performed in the lab using *Standard Method* 3120 B or EPA Methods 200.7, 200.8, 200.9.

13.7.10 UV_{254} Absorbance

Analysis of UV_{254} shall be performed according to *Standard Method* 5910 B. The maximum allowable holding time for *Standard Method* 5910 B is 48 hours. Therefore, it is recommended that UV_{254} samples be analyzed on-site by the FTO with an UV spectrophotometer at 254 nm.

13.7.11 Turbidity

Turbidity analyses shall be performed on-site according to *Standard Method* 2130 or EPA Method 180.1 with either a bench-top or in-line turbidimeter. In-line turbidimeters are recommended for measurement of turbidity in the treated water, and either an in-line or a bench-top turbidimeter may be used for measurement of the feedwater.

During each verification testing period, the bench-top and in-line turbidimeters will be left on continuously. Once each turbidity measurement is complete, the unit will be switched back to its lowest setting. All glassware used for turbidity measurements will be cleaned and handled using lint-free tissues to prevent scratching. Sample vials will be stored inverted to prevent deposits from forming on the bottom surface of the cell.

The FTO shall document any problems experienced with the monitoring turbidity instruments, and shall document any subsequent modifications or enhancements made to monitoring instruments during verification testing.

13.7.11.1 Bench-top Turbidimeters. Grab samples shall be analyzed using a bench-top turbidimeter. Readings from this instrument will serve as reference measurements throughout the study. The bench-top turbidimeter shall be calibrated within the expected range of sample measurements at the beginning of equipment operation and on a weekly basis using primary turbidity standards of 0.1, 0.5, and 3.0 NTU. Secondary turbidity standards shall be obtained and checked against the primary standards. Secondary standards shall be used on a daily basis to check calibration of the turbidimeter and to recalibrate when more than one turbidity range is used.

The method for collecting grab samples will consist of running a slow, steady stream from the sample tap, triple-rinsing a dedicated sample beaker in this stream, allowing the sample to flow down the side of the beaker to minimize bubble entrainment, double-rinsing the sample vial with the sample, carefully pouring from the beaker down the side of the sample vial, wiping the sample vial clean, inserting the sample vial into the turbidimeter, and recording the measured turbidity.

For the case of cold water samples that cause the vial to fog preventing accurate readings, allow the vial to warm up by submersing partially into a warm water bath for approximately 30 seconds.

13.7.11.2 In-line Turbidimeters. In-line turbidimeters must be calibrated and maintained as specified in the manufacturer's operation and maintenance manual. It will be necessary to check the in-line readings using a bench-top turbidimeter at least daily; although the mechanism of analysis is not identical between the two instruments the readings should be comparable. Should these readings suggest inaccurate readings then all in-line turbidimeters should be recalibrated. In addition to calibration, periodic cleaning of the lens should be conducted, using lint-free paper, to prevent any particle or microbiological build-up that could produce inaccurate readings. Periodic verification of the sample flow should also be performed using a volumetric measurement. Instrument bulbs should be replaced on an as-needed basis. It should also be verified that the LED readout matches the data recorded on the data acquisition system, if the latter is employed.

13.7.12 TOC

TOC analyses shall be performed according to *Standard Method* 5310 C. Samples for analysis of TOC should be collected in amber glass bottles with TFE-lined septa supplied by the state or EPA accredited laboratory. The appropriate preservative, as indicated by the state or EPA accredited laboratory, shall be added. The samples shall be shipped overnight with an internal cooler temperature of approximately 4°C to the analytical laboratory. Samples shall be processed for analysis by the state or EPA accredited

laboratory within 24 hours of collection. The laboratory shall then keep the samples at a temperature of approximately 4°C until initiation of analysis.

13.7.13 DBPs Samples

DBPs samples shall be collected, preserved (if applicable), held, and analyzed in accordance with the appropriate *Standard Method*.

13.7.14 Optional Monitoring: Microbial Parameters (Total Coliforms and Heterotrophic Plate Count Bacteria)

Collection of samples for TC and HPC bacteria is optional in this test plan. Samples for analysis of TC and HPC bacteria shall be collected in bottles supplied by the state or EPA accredited laboratory and shipped with an internal cooler temperature of approximately 2-8°C to the analytical laboratory. Samples shall be processed for analysis by the state or EPA accredited laboratory within 24 hours of collection. TC densities shall be reported as most probable number per 100 mL (MPN/100 mL) and HPC densities shall be reported as colony forming units per milliliter (cfu/mL).

13.8 Simulated Distribution System Test Protocol

The SDS DBP test simulates full-scale disinfection by spiking a water sample with a disinfectant and holding the spiked sample in the dark at a designated temperature and contact time. For this testing, one of two SDS approaches may be employed. The conditions selected for SDS evaluation may be those that most closely approximate the detention time and chlorine residual in the distribution system at the site of verification testing. Alternatively, the UFC specified by the ICR will be adopted such that the following set of conditions will be employed:

- Incubation period of 24 +/- 1 hours,
- Incubation temperature of 20 +/- 1.0 °C,
- Buffered pH of 8.0 +/- 0.2,
- 24-hour chlorine residual of 1.0 +/- 0.4 mg Cl_2/L.

For each SDS sample, three incubation bottles will be set up. At the end of the incubation period, each sample will be analyzed for the final disinfectant residual and the sample with the residual closest to the 1.0 +/- 0.4 mg/L range will be used for specified DBP analyses. Analysis for DBPs specified by the manufacturer shall be performed by an State or EPA accredited laboratory according to the *Standard Methods* procedures appropriate for the designated DBPs.

In the case that this verification testing for removal of precursors to DBPs is conducted in conjunction with utility operation, the SDS or DBP formation conditions employed for this test plan may be tailored to correspond to the appropriate SDS conditions at the corresponding utility.

One liter, amber colored bottles with teflon lined caps shall be used to store the SDS samples during incubation. These bottles shall be stored in a temperature-controlled incubator at the specified temperature.

All glassware used for preparation of the reagents shall be chlorine demand free. Chlorine demand free glassware shall be prepared by soaking glassware in a 50 mg/L chlorine bath for a period of 24 hours. At the end of this time, all glassware shall be rinsed three times with organic-free water that has a TOC concentration of less than 0.2 mg/L. Glassware shall then be dried at room temperature for a period of 24 hours. During the drying process, bottle openings shall be covered with aluminum foil to prevent contamination.

The reagents preparation and sample measurement shall proceed as follows.

13.8.1 Chlorine Stock Solution Preparation

The stock solution shall be prepared by adding an estimated volume of 6% reagent-grade NaOCl into a 500-mL, chlorine demand free, bottle containing an estimated amount of organic-free water. To minimize the dilution error, the chlorine stock solution shall be required to be at least 50 times stronger than the chlorine dose required.

13.8.2 Preparation of Additional Chemicals

Refer to *Standard Method* 4500-Cl F for the preparation method of DPD indicator, FAS standard and buffer solution. The phosphate buffer solution shall be prepared as instructed in *Standard Method* 4500-Cl F.

13.8.3 Sample Collection and Incubation

The samples shall be collected in a 1-L amber bottle and stored in the dark at the predetermined temperature. Samples shall be adjusted to pH 8.0 +/- 0.2 using 1M HCl or NaOH and then be dosed with the appropriate dosage of chlorine to yield a chlorine residual of 1.0 +/- 0.4 mg Cl_2/L after the specified 24-hour storage period. The samples shall be capped head-space free and stored for 24 hours in the dark at the appropriate incubation temperature.

13.8.4 Analytical Measurements

Residual free chlorine measurements shall be conducted according to *Standard Methods* 4500-Cl G. DPD Colorimetric Method. Specific parameters to be measured and recorded are outlined in the specific task descriptions.

14.0 OPERATION AND MAINTENANCE

The FTO shall obtain the manufacturer-supplied operations and maintenance (O&M) manual to evaluate the instructions and procedures for their applicability during the verification testing

period. The following are recommendations for criteria for O&M manuals for membrane process equipment that are designed to achieve removal of precursors to disinfection by-products.

14.1 Maintenance

The manufacturer shall provide readily understood information on the recommended or required maintenance schedule for each piece of operating equipment such as:

- Pumps;
- Valves;
- Pressure gauges;
- Backwash controls;
- Flow meters;
- Air compressors;
- Chemical feeder systems;
- Mixers;
- Motors;
- Instruments, such as streaming current monitors or turbidimeters; and
- Water meters, if provided.

The manufacturer shall provide readily understood information on the recommended or required maintenance schedule for each piece of operating equipment such as:

- Tanks and basins;
- In-line static mixers; and
- Tubing and hoses.

14.2 Operation

The manufacturer should provide readily understood recommendations for procedures related to proper operation of the equipment. Among the operating aspects that should be discussed are:
Filtration:

- Control of feed flow to the membrane system;
- Measurement of inlet/outlet pressures and filtrate flows;
- Measurement of transmembrane pressure changes during filter run; and
- Feed flow control in response to temperature changes.

Membrane backwashing:

- Programming automated frequency;
- Proper backwash venting and disposal;
- Appropriate backwash rate (if applicable); and
- Monitoring during return of filter to service.

Chemical cleaning:

- Selection of proper chemical washing sequence;
- Proper procedures for dilution of chemicals;
- Monitoring of pH through chemical cleaning cycle;
- Rinsing of membrane system following chemical clean; and
- Return of filter to service.

Chemical feeders (in the case that chemical pretreatment is applied):

- Calibration check;
- Settings and adjustments -- how they should be made; and
- Dilution of chemicals and polymers -- proper procedures.

Monitoring and observing operation:

- Observation of feedwater or pretreated water turbidity;
- Observation of transmembrane pressure increase between backwashes;
- Filtered water turbidity;
- Filter head loss; and
- What to do if turbidity breakthrough occurs.

The manufacturer should provide a troubleshooting guide; a simple check-list of what to do for a variety of problems including:

- No raw water (feedwater) flow to plant;
- Can't control rate of flow of water through equipment;
- Valving configuration for direct flow and cross-flow operation modes;
- Poor filtrate quality;
- Failed membrane test;
- Low pump feed pressure;
- Automatic operation (if provided) not functioning;
- Filtered water turbidity too high;
- Head loss builds up excessively rapidly;
- Reduced filtrate flux;
- Machine will not start and "Power On" indicator off;
- Machine will not start and "Power On" indicator on;
- Pump cavitation;
- Valve stuck or won't operate;
- No electric power;
- No chemical feed; and
- No antiscalant addition.

The following are recommendations regarding operability aspects of equipment that are designed to achieve removal of DBP precursors. These aspects of plant operation should be considered, if

possible, in reviews of historical data, and should be considered to the extent practical in the discussion on O&M in verification reports of equipment testing when the testing is done under the ETV verification program.

During verification testing and during compilation of historical equipment operating data, attention shall be given to equipment operability aspects. Among the factors that should be considered are:

- Fluctuation of flow rates and pressures through membrane unit -- the time interval at which resetting is needed (i.e., how long can feed pumps hold on a set value for the feed rate?).

- Presence of devices to aid the operator with flow control adjustment and chemical dosage selection:
  - influent and filtered water continuous turbidimeters provided?
  - continuous particle counter provided on membrane filtered water?
  - can backwash be done automatically?

- If automatic backwash provided, could it be initiated by:
  - reaching a set value for head loss?
  - reaching a set value for filtered water turbidity?
  - a preset automatic timer?

- Does remote notification to operator occur when backwash happens?

- Can operator observe backwash?

- Does plant have multiple feed points for chemicals:
  - for pH adjustment?
  - for coagulant chemical feed?
  - for antiscalant addition?

- Is transmembrane pressure measurement provided?

- Is rate of flow of raw water measured?

- Are chemical feeds paced with raw water flow?

- Is backwash rate of flow measured and variable?

- Is backwash duration (time) variable?

The report on verification testing should address the above questions. The issues of operability should be dealt with in the portion of the report that is written in response to Tasks 1 & 2 of the membrane TSTP addressing the removal of precursors to DBPs.

15.0 REFERENCES

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Table 1.
Task Descriptions

Task No.	Task	Testing Periods (minimum)	Issue	Test
Membrane Verification Testing Study				
A	Characterization of Feed Water		Determine physical and chemical characteristics of feed water.	Review historical data and/or analyze feed water samples.
B	Initial Test Runs		Determine system operating conditions that result in effective treatment of feed water.	Perform initial test runs or shakedown testing.
1	Membrane Flux and Operation	1	Rate of specific flux decline.	Evaluate productivity at selected set of operational conditions.
2	Cleaning Efficiency	1	Cleaning efficiency.	Clean system following fouling.
3	Finished Water Quality	1	Finished water quality & rejection capabilities.	Measure permeate WQ and document rejection capabilities.
4	Data Handling Protocol		Careful recording of testing data.	
5	QA/QC		Enforcement of QA/QC standards.	

Table 2.
Operational Data Collection Schedule

Location	Operational Data	Minimum Frequency
Raw Water		
	Flow	2/day
	Temperature	1/day
Single-Stage Membrane Processes		
	Influent module/vessel pressure	2/day
	Effluent module/vessel pressure	2/day
	Permeate pressure	2/day
	Permeate flow	2/day
	Permeate temperature	1/day
	Concentrate flow	2/day
Multiple-Stage Membrane Processes		
	Stage 1 Influent module pressure	2/day
	Stage 1 Effluent module pressure	2/day
	Stage 1 Influent module temperature	1/day
	Stage 1 Feed flow	2/day
	Stage 1 Permeate pressure	2/day
	Stage 1 Permeate flow	2/day
	Stage 1 Permeate temperature	1/day
	Stage 1 Crossflow velocity	2/day
	Stage 1 Effluent module flow	2/day
	Stage 2 Influent module pressure	2/day
	Stage 2 Effluent module pressure	2/day
	Stage 2 Influent module temperature	1/day
	Stage 2 Feed flow	2/day
	Stage 2 Permeate pressure	2/day
	Stage 2 Permeate flow	2/day
	Stage 2 Permeate temperature	1/day
	Stage 2 Crossflow velocity	2/day
	Stage 2 Concentrate flow	2/day

Note: It is recognized that different manufacturer membrane configurations shall have appropriate sampling locations and measurement points according to the particular geometry of the membrane system. Membrane performance will be best evaluated from these sampling points; therefore, this data collection schedule should be adapted to the manufacturer's particular configuration and operational process.

Table 3.
Water Quality Sample Schedule

Parameter	Sampling Frequency	Single Stage Process			Multiple Stage Process				
					Stage 1			Stage 2	
		Feed	Permeate	Backwash Waste	Feed	Permeate	Concentrate	Permeate	Waste
On-Site Analytes									
pH	Daily	1	1	1	1	1	1	1	0
Temperature	Daily	1	0	0	1	0	0	0	0
Turbidity*	Daily	1	1	1	1	1	1	1	1
Laboratory Analytes									
Alkalinity	Monthly	2	2	0	2	2	2	2	0
Total/calcium hardness	Monthly	2	2	0	2	2	2	2	0
Total Organic Carbon	Weekly	2	2	1	2	2	2	2	1
UV_{254} or Color**	Daily	1	1	0	1	1	1	1	0
Total Suspended Solids	Monthly	2	2	2	2	2	2	2	2
Total Dissolved Solids	Monthly	2	2	0	2	2	2	2	0
Ortho-phosphate	Monthly	2	2	0	2	2	2	2	0
Sulfate	Monthly	2	2	0	2	2	2	2	0
Dissolved Iron	Monthly	2	2	0	2	2	2	2	0
Dissolved Manganese	Monthly	2	2	0	2	2	2	2	0
Silica (total and dissolved)	Monthly	2	2	0	2	2	2	2	0
Chloride	Monthly	2	2	0	2	2	2	2	0
Bromide	Monthly	2	2	0	2	2	2	2	0
Conductivity	Monthly	2	2	0	2	2	2	2	0
Silt Density Index	Monthly	2	0	0	2	0	0	0	0
Total coliforms (optional)	Weekly	1	1	1	1	1	1	1	1
HPC (optional)	Weekly	1	1	0	1	1	1	1	0
SDS Testing (Optional Selection of Monitored DBPs)									
Total Trihalomethanes	Per ETV Test	8	8	0	8	8	2	8	0
Haloacetric Acids (6)	Per ETV Test	8	8	0	8	8	2	8	0
Chloral Hydrate	Per ETV Test	8	8	0	8	8	2	8	0
Chloropicrin	Per ETV Test	8	8	0	8	8	2	8	0
Haloketones	Per ETV Test	8	8	0	8	8	2	8	0
Haloacetonitriles	Per ETV Test	8	8	0	8	8	2	8	0
Other specified DBPs	Per ETV Test	8	8	0	8	8	2	8	0

Note: The Field Testing Organization shall equally space samples that are required for the ETV test. For example, if 8 samples are required during the ETV test, then the 8 samples should be equally spaced in time during the ETV test. Similarly, if one sample is required per week during the ETV test, then the samples should be collected on the same day each week.

*Daily batch sampling or continuous monitoring may be employed for measurement of turbidity.

**UV_{254} or color needs to be measured daily; however, at least one measurement per week needs to be UV_{254}.

Note: The manufacturer should adapt the operational data collection location to the particular configuration of the membrane system.

Table 4.
Analytical Methods

Parameter	Facility	*Standard Methods*[1] Number or Other Method Reference	EPA Method[2]
Temperature	On-Site	2550 B	
pH	On-Site	4500-H^+ B	150.1 / 150.2
Total Alkalinity	Lab	2320 B	
Total Hardness	Lab	2340 C	
Total Organic Carbon	Lab	5310 C	
Turbidity	On-Site	2130 B	180.1
Dissolved Oxygen	On-Site	4500-O	
Iron	Lab	3120 B	200.7 / 200.9
Manganese	Lab	3120 B	200.7 / 200.8 / 200.9
UV_{254} Absorbance	Lab	5910 B	
Calcium Hardness	Lab	3500-Ca D	
Total Dissolved Solids	Lab	2540 C	
Total Suspended Solids	Lab	2540 D	
Conductivity	Lab	2510 B	120.1
Ortho-phosphate	Lab	4500P-E	365.1
Sulfate	Lab	4110 B/4500-SO_4^+C, D, F	300.0
Silica (total and dissolved)	Lab	3120 B/4500-Si D, E, F	200.7
Chloride	Lab	4110 B/4500-Cl^- D	300.0
Bromide	Lab		300.0
Total THMs	Lab		502.2, 524.2, 551
Haloacetic Acids (HAA6)	Lab		552.1
Chloral Hydrate	Lab	5710 D	
Chloropicrin	Lab	5710 D	
Haloketones	Lab	5710 D	
Haloacetonitriles	Lab	5710 D	
Other specified DBPs	Lab	5710 D or other specified method	
TC and HPC	Lab	9221 / 9222 / 9223 / 9215 B	

Notes:

1) *Standard Methods* Source: 20th Edition of Standard Methods for the Examination of Water and Wastewater, 1999, American Water Works Association.

2) EPA Methods Source: EPA Office of Ground Water and Drinking Water. EPA Methods are available from the National Technical Information Service (NTIS).

Figure 1
Schematic of Membrane Operational Plan